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A SIMPLE TECHNIQUE FOR RECORDING OPTICAL SIGNATURES

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The observations are compared with the calculations for the image intensity in an appendix.

Details of illustrations in this document may be better studied on microfiche

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A SIMPLE TECHNIQUE FOR RECORDING OPTICAL SIGNATURES

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A simple method of observing and recording the optical signature of a satellite as displayed on a TV monitor is discussed. The technique is applied to the analysis of an ATS-5 synchronous satellite.

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Accepted for the Air Force
Eugene C. Raabe, Lt. Col., USAF
Chief, ESD Lincoln Laboratory Project Office

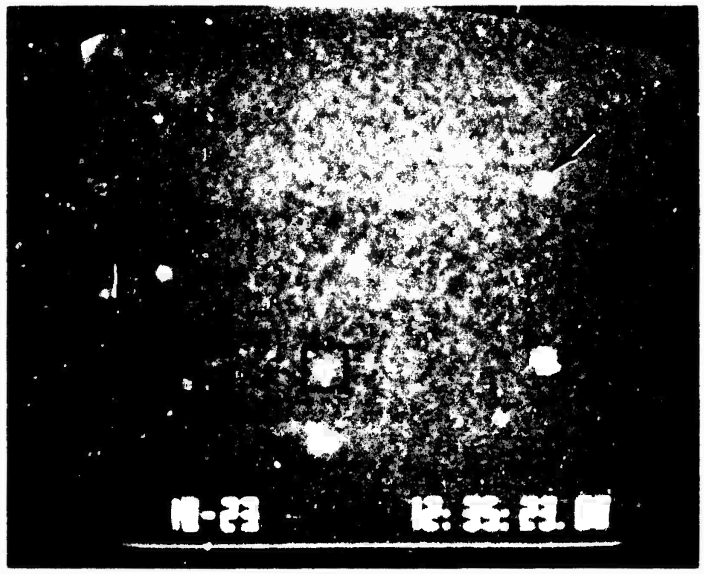
A SIMPLE TECHNIQUE FOR RECORDING OPTICAL SIGNATURES

We have made use of a simple technique for observing and recording optical signatures of satellite images. It appears that the technique may be useful, at least in certain favorable circumstances, for obtaining the signatures of satellites with rotation rates on the order of one-half second and longer and bright enough not to be obscured by noise.

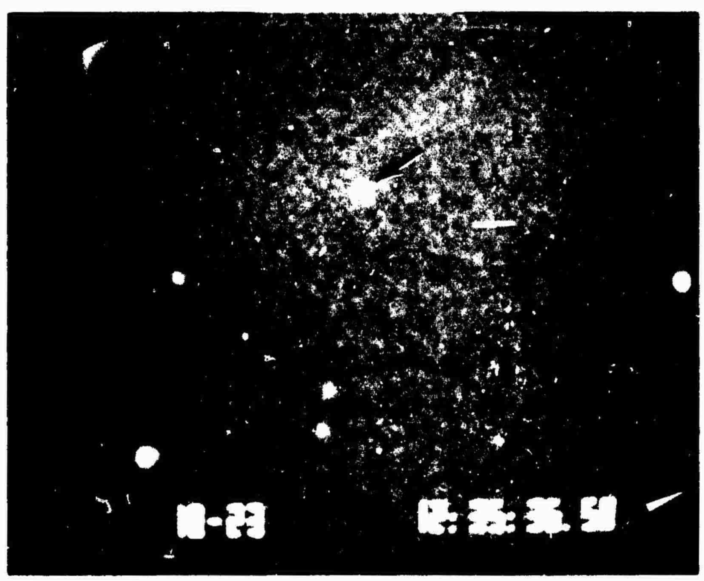
Video tape recordings were made of telescope images focused on the photo-cathode of a silicon image intensifier camera tube for later more extensive analysis and processing. Figure 1 is a photograph of the result as displayed on a TV monitor. In the figure the satellite image is indicated by an arrow in both cases. It will be noted that the star background has moved with respect to the satellite between the two images. In this example of a synchronous satellite, the telescope was simply pointed at the satellite. In other cases the telescope might be on sidereal drive following the stars and then the satellite would move across the screen.

The satellite shown in Figure 1 is an ATS-5 (a NASA Application Technology Satellite in 1 × synchronous orbit launched in 1969) and was plainly seen to scintillate in a regular pattern in the TV presentation. The pattern was too rapid to follow with the naked eye, having a repetition rate greater than once per second.

With a video tape recorder, it is possible to display repeatedly a single field, and with an oscilloscope one can observe a single line or succession of lines in that single field. Figure 2 shows an expanded trace of a single line of the raster. The peak in the curve shows the intensity of the satellite image on that line of the raster. In Figure 2a, the satellite image is at its brightest and in Figure 2b at its weakest. Since the image of the satellite is spread over more than one line, it is useful to observe several lines at the same time. Such a presentation is shown in Figure 3, where eight successive lines are shown in each for both a dim image (Figure 3a) and a strong image (Figure 3b). The height of the spikes in each line is, of course, proportional to the satellite image intensity in that field. Since the TV image can be

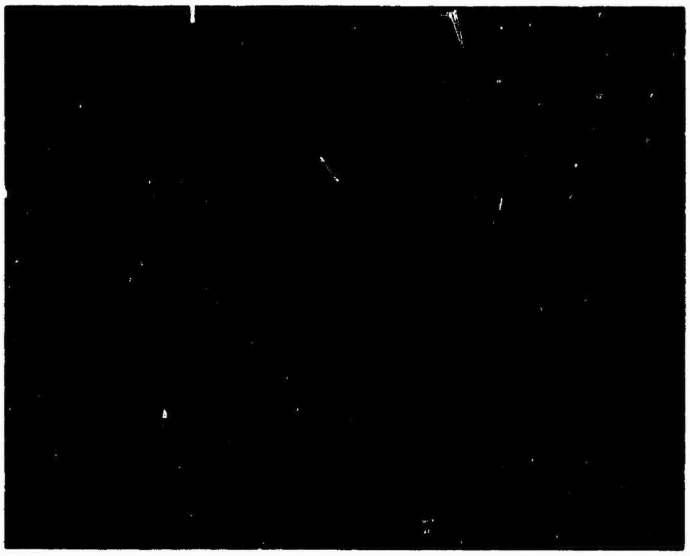


(a)



(b)

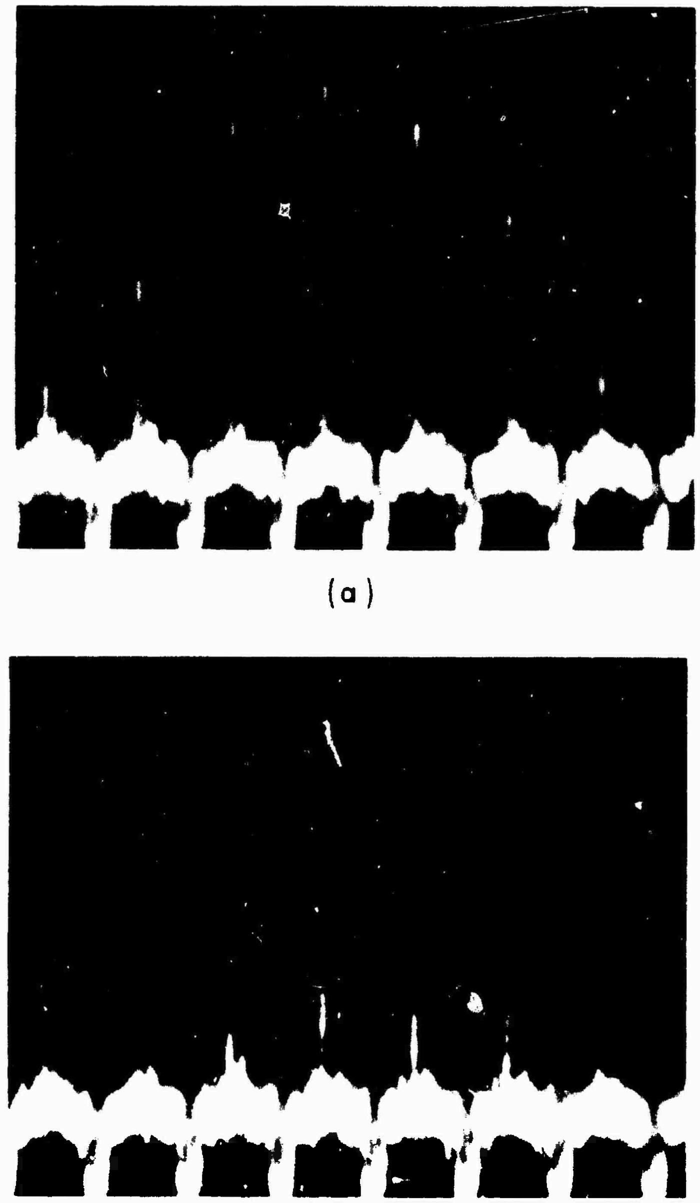
Fig. 1. Satellite image with moving star background as seen on TV monitor. Figures 1a and 1b were taken at different times as shown by the time at the lower right of the screen. The satellite is indicated by the box in each photograph and the apparent star movement is shown by identification (by the arrow) of the same star in both photographs.



(a)

(b)

Fig. 2. Oscilloscope photographs of a portion of a single line from raster on TV monitor showing image intensity of satellite as shown in Fig. 1. (a) scanning strongest image and (b) scanning weakest image. Time (horizontal) scale is 0.5 μsec/div



(a)

(b)

Fig. 3. Same as Fig. 2., except time (horizontal) scale has been changed to 50 μsec per major division, thus showing approximately eight lines from the raster.

examined field by field and since the field rate is known (60 per second), a measure of the intensity versus time can be obtained.

A measurement of the satellite image intensity, shown in Figure 4, was obtained by assuming that the intensity was proportional to the height of the pulse and the total image intensity was obtained by summing the pulse heights over the six to eight lines spanned by the image. The time covered is two seconds, which required a total of 120 photographs. It will be noted that the intensity pattern repeats, with a repetition time of 0.8 second. This is in agreement with the known rotation rate of the ATS-5 satellite. The horizontal axis can be scaled in terms of the rotation angle. This is shown in the upper boundary of the figure. The sharp increases in intensity are seen to repeat at 180-degree intervals or twice for every 360-degree rotation of the satellite. The broader feature repeats once for every 360-degree rotation. It is probable that the sharp intensity spikes are due to specular reflections off the cylindrical body of the satellite, while the broader feature is a diffuse reflection from a set of planar arrays mounted on the body of the satellite. Detailed knowledge of the location of the satellite with respect to the sun and the observer and details of the satellite construction are necessary to fully understand the optical signature observed.

A simpler and faster method of obtaining the same information is to make use of a broad-area photodetector. The photodetector can be placed, or held by hand, directly on the face of the TV screen over the satellite image. The photodetected signal can then be displayed on an oscilloscope and photographed.

We used a silicon photodiode with an active area diameter of approximately 8 millimeters and a bias voltage of 45 volts. Since the response time of silicon photodiodes is much faster than the 1/60-second field rate of the TV presentation, the output circuit has to incorporate a large RC time constant (RC ≈ 1 msec). A circuit schematic is shown in Figure 5.

A sample photograph of the image intensity versus time taken in this manner is shown in Figure 6. In the figure, the time (horizontal) scale is 0.2 sec per major division, giving the same rotation rate as shown in Figure 4. In the figure each vertical

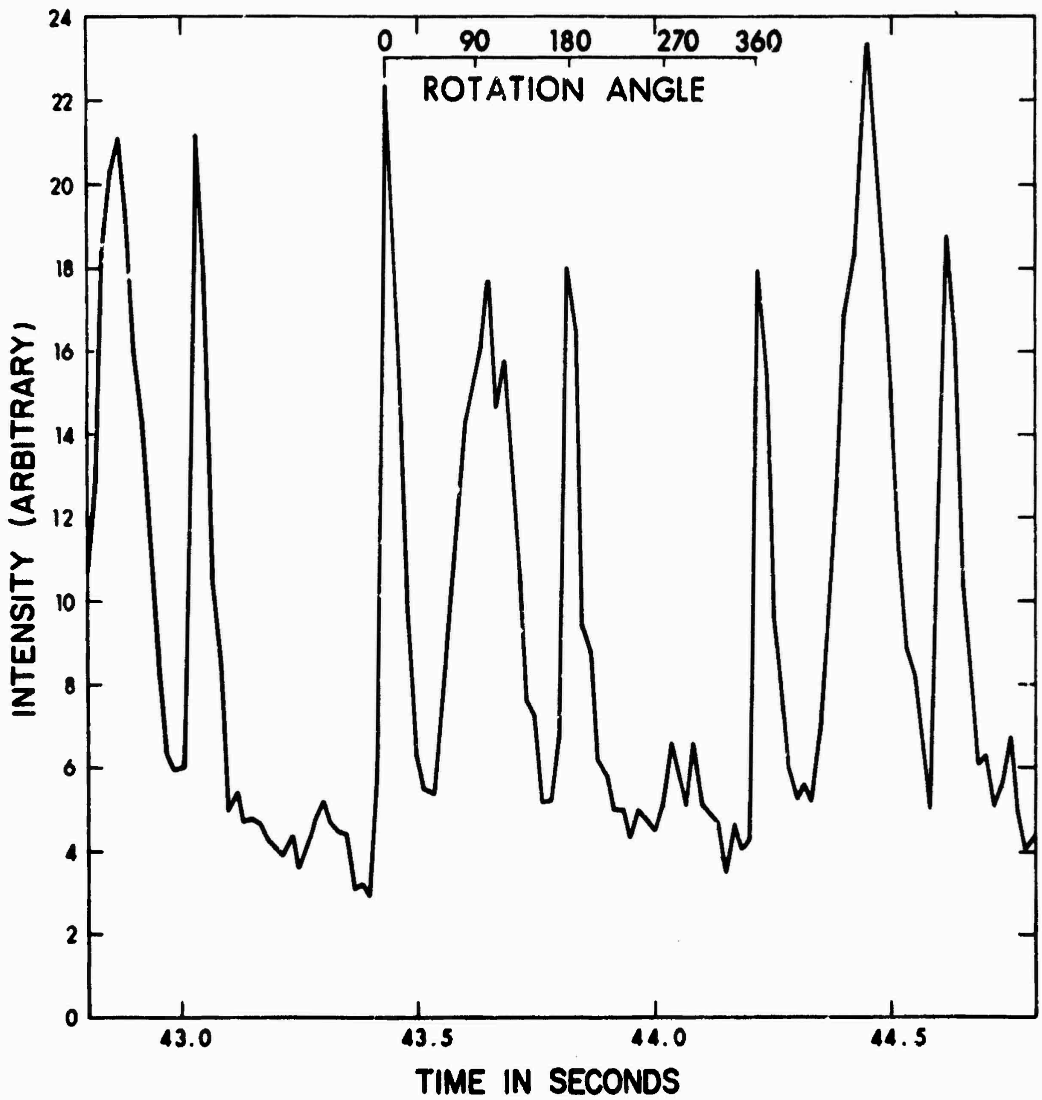


Fig. 4. Relative intensity versus time.
ATS-5, Phase angle ≈ 90°, Oct.

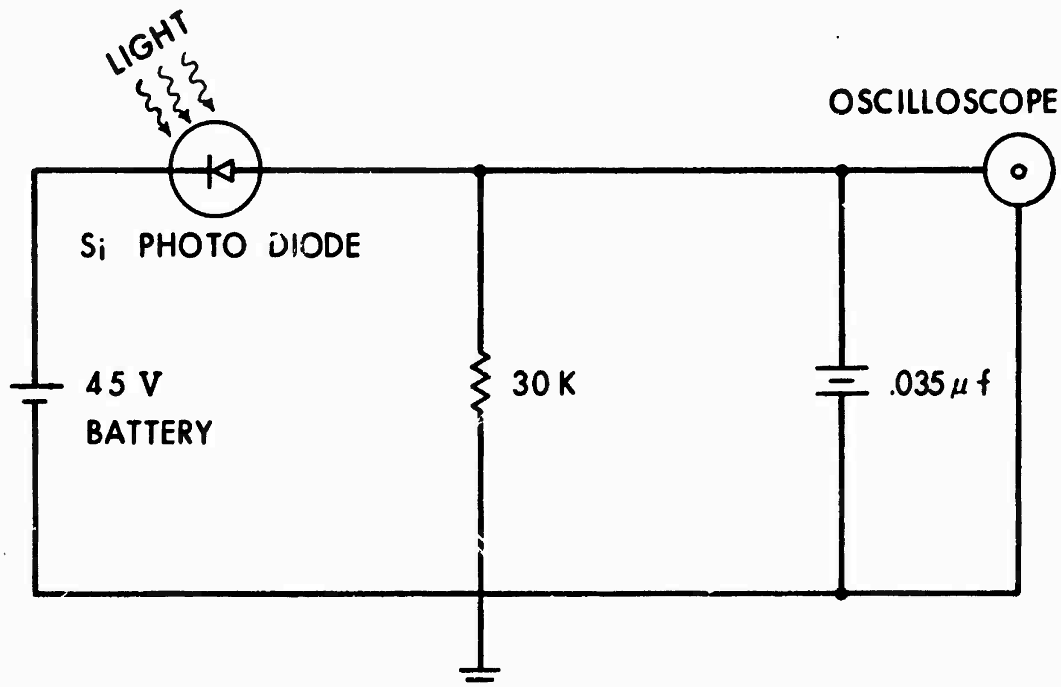


Fig. 5. Schematic for photodetector measurements.

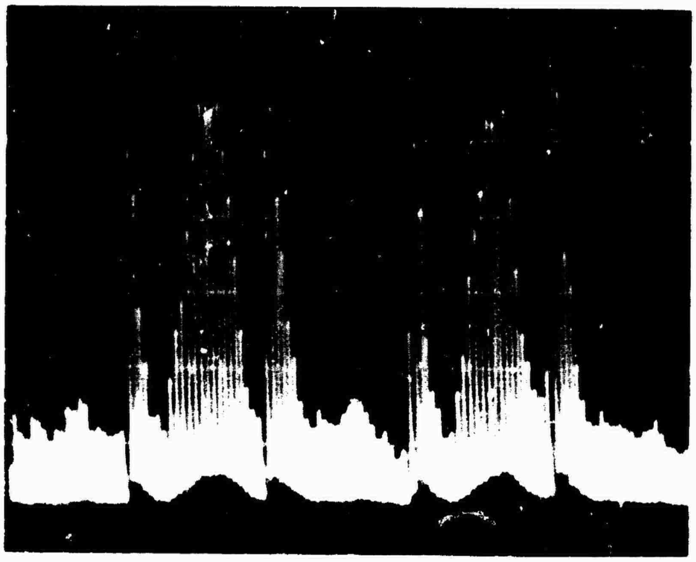


Fig. 6. Photometer recording of satellite intensity. Horizontal scale = 0.2 sec/div. ATS-5, phase angle ≈ 90°, October.

spike represents the intensity in a single field of the TV presentation. All of the principal features of the manually obtained signature are observed in the photodetector presentation including the small intensity increases between the two sharp components. Figure 7 shows a photo taken with a time scale of one second per major division showing many cycles of the optical signature. Figure 7 also shows, in the low flat portion near the center, the background intensity of the TV presentation.

It should be pointed out that the photodetector technique is useful for relative measurements only. The brightness of the TV image is a function of the settings on the brightness, contrast, and restoration controls of the TV monitor. However, this does allow one to emphasize certain aspects of the presentation, for example, by increasing the contrast ratio to amplify small variations in the optical signature. It is also possible to get visible magnitudes by measuring the image intensity of a known star of a similar magnitude in the vicinity of the satellite.

In both the intensity curves (Figures 4 and 6), the sharp specular reflections are seen to rise very rapidly, usually in the time of a single frame, while the trailing edge drops off much more slowly. This is apparently due to the persistence of the imaging system. Scintillations, which can also be observed in the same manner, are also observed to rise in a single frame and then drop off more slowly.

The satellite observations shown in the previous figures were made in October 1973 from Flagstaff, Arizona, when the satellite and the sun were in position to give specular reflections at the observing site. An earlier observation (April 1973) was made from the same site, but in this case the sun was not in position to be observed specularly from the observing site. A photo showing the optical signature as observed in April is shown in Figure 8. Even though the signal level in April was much lower (as indicated by the high background signal shown in Figure 8) than seen in Figures 4 and 6, it is clear that only the broad reflection is observed. This supports our interpretation that the sharp intensity spikes are specular reflections and the broad reflection is a diffuse reflection, probably off the planar arrays on the body of the satellite.

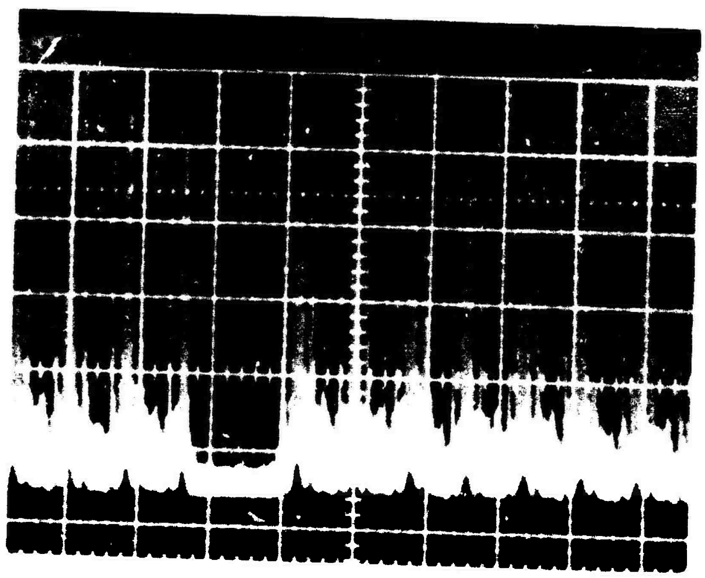
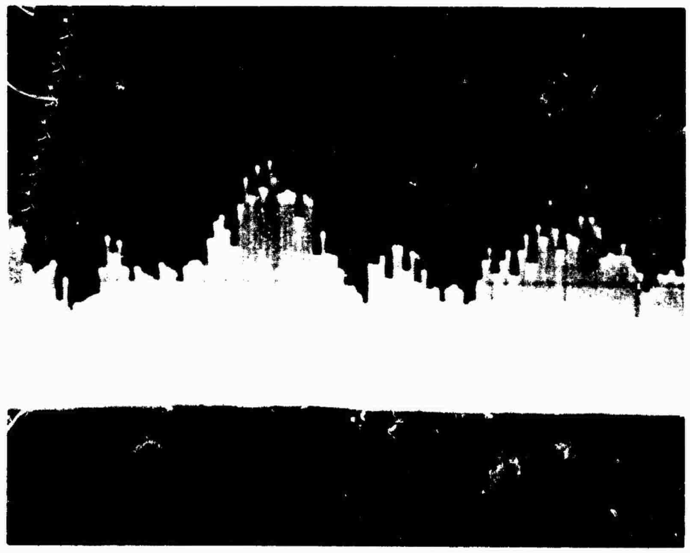
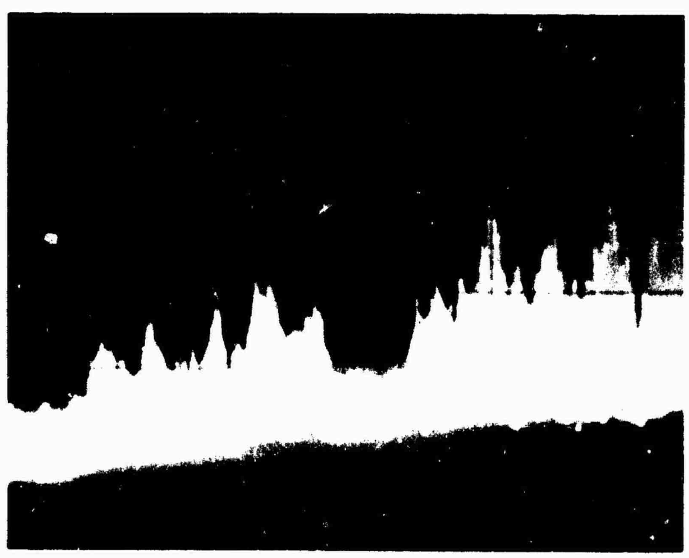


Fig. 7. Photometer recording of satellite intensity. Horizontal scale = 1.0 sec/div. ATS-5, phase angle ≈ 90^o, October.



(a)



(b)

Fig. 8. Photometer recording of satellite image intensity. ATS-5, phase angle ≈ 90^{o}, April. (a) horizontal scale = 0.2 sec/div. (b) horizontal scale = 1.0 sec/div.

A simple, but useful, technique has been devised for the recording and analysis of the optical signature of satellite images. These optical signatures were observed to vary with the time of year and observation conditions. While the signature was photographed from an oscilloscope, there is no reason why the signature could not be recorded on an x-time recorder such as the Visicorder and thereby record the signature over long periods of time.

With these observations, it has become clear that while the diffuse reflections appear to be relatively simple to understand and calculate, the specular flashes require specific and detailed calculations making use of satellite physical characteristics as well as illumination conditions. On the other hand, the sharpness and regularity of the specular flashes give significant information, such as rotation and structural complexity, about the satellite. Observations made at various times as well as from different sites (both give different [illegible]-satellite-observer geometries) can be expected to show different optical signatures.

This preliminary analysis of the data was made with video recordings prepared and made available to us by Robert Weber and Thomas Brooks. We wish to thank Norman Pong for technical assistance in this experiment. We also wish to thank J. E. Gifford of the Westinghouse Corporation, and assigned to the Goddard Space Flight Center, for information on and photographs of the ATS-5 satellite.

APPENDIX A

The ATS-5 satellite, a partial view of which is shown in Figure A1, is a cylinder 1.83 m high and 1.43 m in diameter. It is in a circular, $1 \times$ synchronous orbit with its rotation axis oriented approximately parallel to the earth's polar axis. Approximately two-thirds of its cylindrical surface area is covered with silicon solar cells, which have a diffuse reflection coefficient of 0.07 and a specular reflection coefficient of 0.15.[1]

The visual magnitude of a resident space object (RSO) illuminated by the sun is[2]

$$m_v = -26.78 + 5 \log R - 2.5 \log \rho A - 2.5 \log F(\Phi)$$

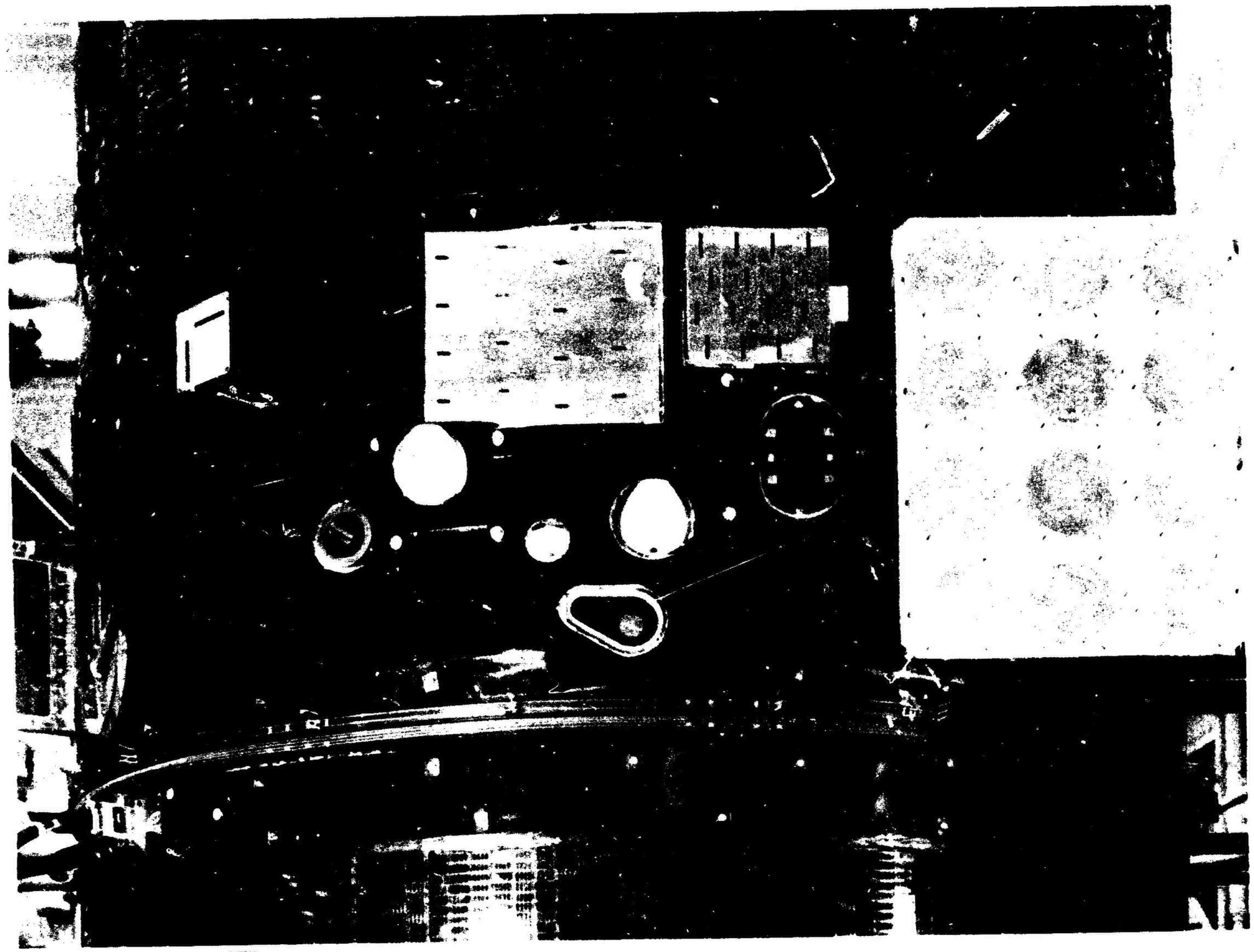
where -26.78 is the visual magnitude of the sun at the earth, R is the observer to satellite distance, ρ is the reflectivity of the RSO reflecting surface, A is the cross-sectional area of the RSO, and $F(\Phi)$ is a phase function which depends on the relative orientations of the sun, observer, satellite, RSO axis and the shape of the reflecting surface. We use $R = 37,100$ km in the following calculations. Then

$$m_v = 11.07 - 2.5 \log \rho A - 2.5 \log F(\Phi) \ .$$

Using these expressions and Table I from McCue _et al._[2], the visual magnitude of the reflections due to the separate parts of the ATS-5 satellite can be calculated.

(1) The diffuse reflection from the two cylindrical banks of solar cells.

The reflectivity-area product is $2 \times .07 \times 1.43 \times .6 = 0.12$. With a phase angle of 90° (as was the case for both the April and the October observations), an angle of 11° for the latitude of both the sun and the observer from the plane normal to the cylinder polar axis, the phase function $F(\Phi)$ is



NASA G-70- 570

Fig. A1. Photograph of center section, NASA, ATS-5 satellite.

$$F(\Phi) = \frac{\cos\phi_1 \cos\phi_2}{4\pi} \left[(\pi - \theta)\cos\theta + \sin\theta\right] = 0.0767$$

for a diffusely reflecting cylinder. This is a visual magnitude of $m_v = 16^m.1$, and should be the base intensity of the satellite as its rotates, as viewed in both April and October.

(2) The specular reflection from a line of solar cells.

A typical solar cell is 2 cm wide by 1 cm long, and in this case a line of cells is 0.6 m long. The reflectivity area product is $0.15 \times 0.02 \times 0.61$. The phase function for a specular reflection from a flat plate is

$$F(\Phi) = \frac{4\cos(\Phi/2)}{\pi \Delta^2}, \text{ where } \cos\Phi = \sin\phi_1 \sin\phi_2 + \cos\phi_1 \cos\phi_2 \cos\theta .$$

ϕ_1 and ϕ_2 are latitudes of the sun and the observer measured from the plane surface, θ is the phase angle, and Δ is the angular dimension of the sun as viewed from the satellite (Δ = .0093 radians). This leads to a visual magnitude $m_v = 7^m.7$ for the specular flash from the line of solar cells. But, if the normals to the solar cell surfaces are distributed over 1^o, the visual magnitude is reduced by $\Delta m_v = 5^m$, and the observed flash would have a magnitude of $12^m.7$. The apparent magnitude of the specular flash as observed by the TV image monitoring technique described in this report would be lowered still further because of the 1/60-sec, or 7.5 angular degrees, integration of the TV imaging system.

Since the ATS-5 was oriented, and the sun was located, in a position to give specular reflections off the cylinder surface in the direction of the observer in the October observations, but not in the April observations, and since there is a small nutation of the cylinder axis about the axis of rotation, the sharp peaks in the intensity of the satellite image are probably due to specular reflections off the solar cells.

(3) The diffuse reflection from the planar arrays.

The dimensions of the largest planar array (Figure A1) appear to be approximately 0.4 m × 0.3 m with the other arrays having an area of about half the main array. Assuming a diffuse reflection coefficient for these surfaces of 0.5, the reflectivity area product is $\rho A = 1.5\ (0.5 \times 0.4 \times 0.3)$. The phase function $F(\Phi)$ for diffuse reflection from a flat plate is

$$F(\Phi) = \frac{1}{\pi} \sin \phi_1 \sin \phi_2 \quad .$$

When the phase angle is 90° and the sun-satellite and observer-satellite vectors are in a plane normal to the flat surface, as they were in the October observations, $\phi_2 = 90 - \phi_1$. The maximum occurs when $\phi_1 = \phi_2 = 45^\circ$, giving a value $F(\Phi) = 0.159$. The maximum visible magnitude for the planar arrays for this geometry is then $m_v = 15^m.7$. For the April observations the plane containing the sun-satellite and observer-satellite vectors was approximately 11° off the normal, which does not lead to significantly different results.

The angular variation of the diffuse reflection toward the observer for a phase angle of 90°, as the satellite rotates on its axis, is shown in Figure A2. As shown by the dashed line, the half intensity width is 60° and the intensity goes to zero at a width of 90°. This is in agreement with the width of the broad maximum shown in Figures 4 and 6 and appears to be consistent with the data of Figure 8. We associate the broad feature of the image intensity data as a diffuse reflection from the planar arrays as shown in Figure A1.

For a phase angle of 0° and otherwise the same geometry, $\phi_1 = \phi_2$ and varies between 0° and 90°. Then the phase function for the flat plate is

$$F(\Phi) = \frac{1}{\pi} \sin^2 \phi_1 \quad .$$

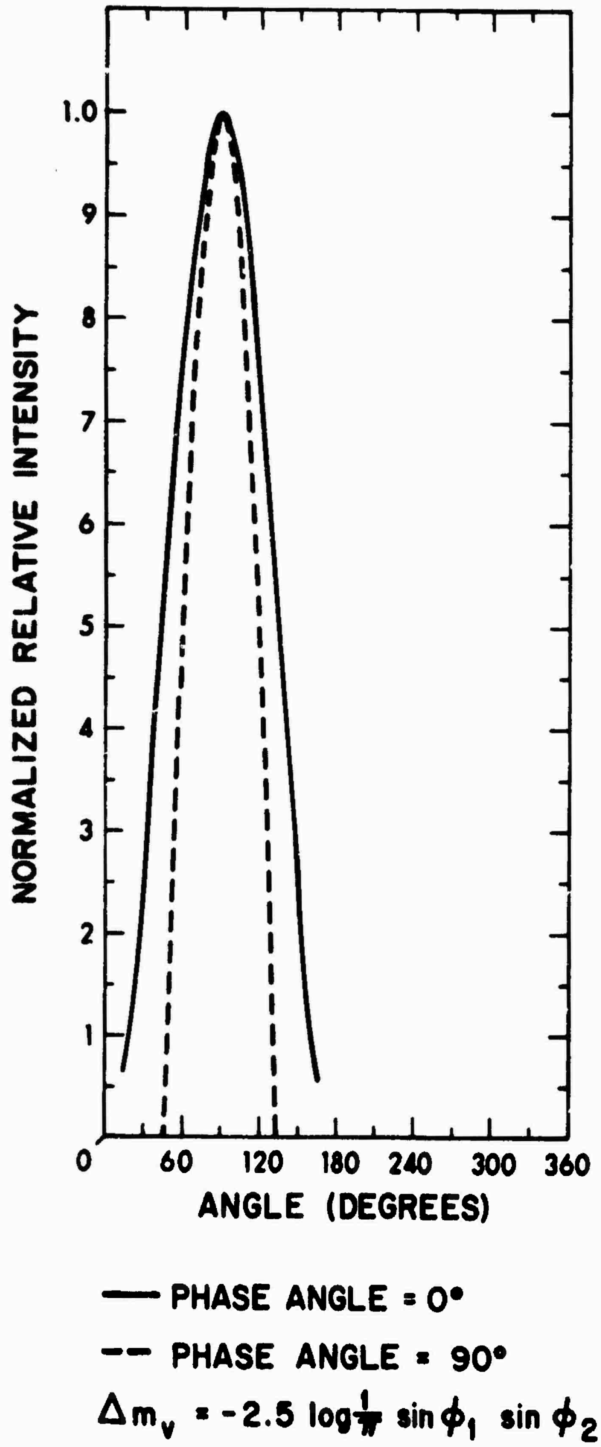


Fig. A2. Normalized intensity versus angle for diffusely reflecting flat plate.

The angular variation is shown in Figure A2, normalized to the 90^{o} phase angle curve. For this case the half intensity width is 90^{o} and the wings go to zero at 180^{o}. It would be very interesting to make an observation of the ATS-5 satellite to verify this prediction.

In summary, a constant base image intensity of $m_v = 16^m$ is calculated for the rotating satellite. The intensity increases to 15^m when the planar arrays are observed at maximum and there are strong specular flashes from the solar cells at special times of the year due to the nutation of the satellite. These calculations appear to be in at least qualitative agreement with the observations.

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